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Introduction

In an effort to reduce the amount of herbicide lost with sediment and water in runoff from a field, farmers are considering using best management practices (BMP's) related to land, crop, and pesticide management. Conservation tillage, pesticide incorporation, contour farming, filter strips and setbacks from water, terraces, contour farming, and pesticide application timing are just a few of the BMP's that could be considered. These practices allows farmers to be competitive in the market, as well as allowing them to effectively use fertilizers and pesticides with minimal losses to the environment. One BMP being strongly recommended today is the use of vegetative filter strips and/or buffer strip. Vegetative filter strips can be defined as a strip of land that lies between the runoff area from a field and the runoff exit or drainage site at the edge or within the field. For example, a strip of grass might be placed between a fields watershed and a stream, or a strip may be placed radially around a tile inlet within a field. The benefits of such a strip would be the filtering effects of sediment and pesticides as the runoff passes over the grass. The roughness of the grassed surface would also slow down the runoff velocity, allowing potential for increased infiltration and sedimentation. Buffer strips can be defined as an area where no chemical has been applied so as to act as a buffer between an chemically applied area and a point of departure from the field. This could also be defined as a setback area. For the remainder of this paper, the term buffer strip, with or without vegetation, will be used for simplification.

Some chemical companies have taken the lead in encouraging the use of buffer strips. Ciba-Geigy and Dupont have recently change their labels for atrazine and cyanazine to include a 20.1 m (66') buffer strip between runoff from a field and any intermittent stream. This strip can be either grassed, cropped, or left bare. With these changes, new research has been conducted at Iowa State University to determine the effectiveness of these strips in reducing herbicide losses associated with runoff.

Literature Review

Very little research has been performed dealing with buffer strip and herbicides until the last two years. Most of the research that has looked at buffer strips, has looked mainly at the effects on reducing nutrient and sediment losses from feedlots (Bingham et al., 1980;Dillaha et al., 1989;Magette et al., 1989;Young et al., 1980). Three other studies did looked at the effectiveness of vegetative strips on reducing losses of 2,4-D, trifluralin (Treflan), and atrazine (Asmussen et al, 1977; Rhodes et al., 1980; Hall et al., 1983). Each of these three studies will be discussed in more detail below.

Asmussen et al. conducted research on the reduction of 2,4-D in runoff as it passed through a grassed waterway. The waterway was 4.6 m x 24.4 m, consisting of bermudagrass and bahiagrass. The soil class was Cowarts loamy sand. 2,4-D was applied at a rate of 0.56 kg/ha to corn plots with an area of 30.2 m^2. The field drainage area to grassed buffer strip was therefore 1:3.72. Rainfall was simulated at a rate of 25.4 mm/h for 30 minutes on the corn plots. Rain water was applied under dry and wet antecedent soil conditions for both the corn plots and the waterway. Table I. shows the reduction of the runoff(water), sediment, 2,4-D in both the water phase and sediment phase, and total 2,4-D. The grassed waterway was shown to be effective in reducing 2,4-D in the plot runoff by approximately 70%.

Table I. Reduction in water, sediment, and 2,4-D in the grassed waterway (Asmussen et al., 1977)

	% Reduction	
	Dry condition	Wet condition
Runoff(water)	50	2
Sediment	98	94
2,4-D in water phase	71	69
2,4-D in sediment phase	>99	>99
Total 2,4-D	72	69

Another study, conducted by Hall et al. (1983) reported the percent atrazine lost in runoff water and sediment from runoff plots with a 14% slope on Hagerstown silty clay loam soil. Atrazine was applied at two rates, 2.2 kg/ha and 4.5 kg/ha, either as a preemergence (PRE) or pre-plant-incorporation (PPI) application method on corn plots. The plots measured 1.8 wide by 22 m long, with five plots corn only and four plots of corn with a 6 m oat strip located within the plots, located at the bottom of the plot. Two replications of each application rate and method was used. One of the corn plots was used as a check treatment. The results are given in Table II for three months in the summer under natural rainfall.

Table II. Percent reduction in atrazine using oat strips (Hall et al., 1983).

	%Reduction		
	Water	Soil	Total
PRE/2.2 kg/ha	85.3	100	90.6
PRE/4.5 kg/ha	59.5	83.8	65.5
PPI/2.2 kg/ha	64.8	66.7	64.9
PPI/4.5 kg/ha	82.3	83.3	82.4

As can be seen from Table II, the reduction of atrazine was found to be significant when passing the runoff through the oat strips. Hall et al. concluded that "Maximum reduction of water, soil, and atrazine losses from this hillside was achieved with a conventional-tillage management system that combined pre-plant-incorporation of atrazine residue with strip cropping on the plot tiers. This system reduced atrazine losses in runoff water and sediment by 87-97%, compared with the preemergence-spayed, non-stripped plot tiers."

Rhodes et al. (1980) also conducted a study on the effectiveness of a 26.4 m waterway in reducing trifluralin transported in surface water runoff from a small watershed. Annual losses were low, being 0.17 and 0.03 percent of that applied for two years of measurements under natural rainfall. When runoff caused by rainfall simulation was directed onto the grassed strip, trifluralin losses were reduced by 96 percent if the strip was dry, and by 86 percent if it was pre-wetted. Over half of this reduction was attributed to adsorption on vegetation, organic matter, and soil. Trifluralin has a high adsorption coefficient, and tends to be lost more with sediment when compared to more moderately adsorbed chemicals like atrazine and cyanazine.

Current Iowa State University Research on Buffer Strips

Although the previous studies have shown significant benefits of using vegetative buffer strips in reducing herbicide losses, they also have used relatively small field area to buffer area ratios on fairly sandy textured soils. All of these studies had ratios smaller than 4:1. Since most farmers would have a difficult time setting aside 0.4 ha (1 acre) of buffer strip area for every 1.6 ha (4 acres) of cropland, a more realistic ratio needs to be considered. Current studies at Iowa State University have looked at ratios from 5:1 to 30:1. Other buffer strips factors have also been evaluated. Four of these studies are summarized in the following sections.

A. Buffer Strips for Controlling Atrazine Runoff Losses (5:1 and 10:1 area ratios)
In the summer of 1992, Mickelson and Baker (1993) setup three replication of grassed (59% smooth Broke, 35% Kentucky bluegrass, and 6% Kentucky 31 tall fescue) buffer strips representing field drainage area to buffer strip area ratios of 5:1 and 10:1, and representing runoff from either a no-tillage field or a conventional tillage field. Six plots were 1.5 m x 4.6 m and the other six were 1.5 m x 9.1 m. Figure 1. shows the typical plot layout. Runoff was added to the top of the plots using 6.4-cm x 1.5-m PVC pipe with holes drilled every 7.6 cm along the pipe. Water was supplied to the distribution pipes from 2000-l cylindrical water tanks. A runoff concentration of 1 ppm was prepared before each rainfall simulation event in the tanks.

No-tillage runoff water contained no sediment, while the conventional tillage runoff water contained ~10,000 ppm of sediment. Simulated rainfall was add to the plots, with a 15.2 m (50') diameter rotating boom rainfall simulator, at an intensity of 66 mm/h for one hour. Simulated runoff was added to the top of the plots after 10 minutes of wetting rain. This inflow, to the top of the plots, was added to represent runoff from an area at 2.5 cm/h for approximately 50 minutes. Both the inflow and the outflow were sampled overtime for atrazine and sediment concentrations. Total inflow and outflow volumes were also determine. From this data, the percent reduction of atrazine and sediment in overland flow by the grassed buffer strips was calculated (Table III.). Both the 5:1 and 10:1 area ratio plots were effective in reducing the sediment from the conventional tillage plots, with over 70% of the sediment retained in the plots. The 5:1 area ratio plots were able to significantly reduce the atrazine losses when compared to the 10:1 plots. There was no significant difference between reductions of atrazine with the no-tillage runoff plots versus the conventional tillage runoff plots. This can probably be attributed to the fact that atrazine is moderately adsorbed to the sediment, and is lost mainly with runoff water.

Table III. Percent reduction of atrazine and sediment with 5:1 and 10:1 area ratios.

Simulated Tillage	Area Ratio	Percent Reduction Atrazine	Percent Reduction Sediment
NT	10:1	35.0%	---
NT	5:1	59.5%	---
CT	10:1	28.3%	72.2%
CT	5:1	51.3%	75.7%

B. Effectiveness of vegetative buffer strips in reducing atrazine, metolachlor, and cyanazine in runoff (15:1 and 30:1 ratios)

This study, conducted by Misra et al. (1994) in the summer of 1993, used procedures very similar to the previous study. The objectives were to determine the effects of high and low inflow concentration (0.1 and 1.0 ppm) and relative drainage area to buffer strip area (15:1 and 30:1) on the efficiency of grassed buffer strips in removing atrazine, metolachlor, and cyanazine dissolved in runoff water. Simulated rainfall, with an intensity of 6.35 cm/h, was applied to the plots for 15 minutes, before runoff was added to the plots, and then for an additional 45 minutes after this inflow began. Each of the plots was 1.5 m by 12.2 m, with a 2 to 3% slope. The grass was 100 Brome grass. The field layout is shown in Figure 2. Inflow and outflow samples were collected and analyzed for herbicide concentrations. Total inflow, rainfall, and outflow volumes were also calculated. The buffer strip efficiency in herbicide removal for the different area ratios and inflow concentrations is given in Table IV.

Table IV. Buffer strip efficiency in herbicide removal with 15:1 and 30:1 area ratios.

Area Ratio	Inflow Con.	Atrazine Removal	Metolachlor Removal	Cyanazine Removal
15:1	0.1 mg/L	31.2%	32.0%	26.2%
15:1	1.0 mg/L	49.8%	46.8%	46.8%
30:1	0.1 mg/L	26.4%	27.4%	25.6%
30:1	1.0 mg/L	47.8%	41.7%	42.4%

Misra et al. noted that infiltration was one of the main factors for reduction of herbicides within a treatment. The greater the infiltration, the greater the herbicide removal. Although there was no significant difference in herbicide removal between the 15:1 and the 30:1 area ratios, there was a significant difference found between having high inflow concentration (1.0 mg/L) as compared to low inflow concentration (0.1 mg/L), with greater retention with the higher concentration.

C. Evaluating herbicide removal by buffer strips under natural rainfall (15:1 and 30:1 area ratios)

Arora et al. (1993) set up a study to look at the efficiency of buffer strips for herbicide removal from surface runoff under natural rainfall, and to determine the effects of the drainage area relative to the buffer strip area of 15:1 and 30:1 on the efficiency of the buffer strip herbicide removal. The same herbicides from the previous study were applied on a 0.41 ha field, planted up and down the slope to corn. The slope of this field was 3%. The soil was classified as a Nicollete silt loam. Atrazine, metolachlor, and cyanazine were sprayed on this source area at a rate of 2.12, 2.80, and 3.36 kg/ha, respectively. Runoff from this area was directed by soil berms to a mixing chute, that then directed the flow to a 3.05 m diameter and 0.76 m deep collection tank. From this tank the runoff water was then distributed to six 1.5 m x 20.1 m grassed buffer strips (87% Brome grass, 11% Blue grass, and 2% other grasses), three at a flowrate representing the 30:1 area ratio and the other three at a flowrate representing the 15:1 area ratio. These area ratios were accomplished by attaching either 30^{o} or 59^{o} V-notch weirs, at equal elevation, around the tank wall. The weir angle ,along with depth data, were used to determine runoff flow volume passing through to the plots. Galvanized chutes carried the runoff from the V-notch weirs to the appropriate plot.

At the bottom of the plot, the runoff was recollected in tanks with dimension of 1.52 m x 0.61 m x 0.76 m. The same shaped V-notch weir at the top of the plot was attached to the side walls of this tank to determine the outflow rate of the runoff. The field and plot setup is shown in Figure 3. ISCO automatic samplers were placed at the inflow tank and at each outflow tank for sampling runoff during a rainfall event. A C-10, Campbell Scientific Datalogger was used to record the temperature and the depth measurements for latter volume calculations. The reduction in sediment and herbicides for the first event that took place (12.7 mm rainfall event) at the site is given in Table V.

Table V. Reduction of sediment and herbicides for the first runoff event following herbicide application.

Area Ratio	Sediment Reduction	Atrazine Reduction	Metolachlor Reduction	Cyanazine Reduction
15:1	45.8%	12.4%	27.3%	21.1%
30:1	40.6%	.34%	15.3%	7.23%

By doubling the drainage area to buffer strip area ratio, both the sediment reduction and the herbicide reduction were decreased. This is most likely due to the fact that with the 15:1 area ratio plots,13.0% of the runoff was infiltrated as compared to only 3.9% for the 30:1 area ratio plots. The higher removal rate for metolachlor can partially be attributed to its higher adsorption rate to living and dead organic matter.

D. Effects of soil incorporation and setbacks on herbicide runoff loss from a tile-outlet terraced field

With the changes in the labeling for atrazine and cyanazine, in the last couple of year, to reduce annual application rates and to require a 20.1 m (66') buffer strip or application setback between the treated area and a surface water resource; corn growers have become concerned with what this means for those of them who have tile-outlet terraced fields (that drain directly into a surface water resource). The EPA indicated that standpipes or surface inlets in a tile outlet system are considered a discharge point requiring a setback if the end of the tile drainage system was not more that 20.1 m from a stream or river. Since inlets for terraces are close to the terrace bank and since farmer typically plant parallel to the terraces, a setback area of 20.1 x 40.2 m (66' x 132') is necessary to meet the EPA's requirement.

The objectives of a study conducted by Mickelson et al. (1984) were to determine if alternative BMP's to the setback could reduce herbicide runoff losses as much or more, without the perceived increased economic costs and hardship of the setback. Three management practices were put into place on six isolated subwatershed areas draining to six individual intakes in two terraces on the Smith farm near Knoxville, Iowa (Figure 4). The treatments included: 1) herbicides preemergence surface broadcast applied without incorporation to the whole subwatershed area (no setback); 2) herbicides preemergence surface broadcast applied without incorporation to the watershed area , excluding a 20.1 m x 40.2 m setback adjacent to the standpipe (setback); and 3) herbicides pre-plant surface broadcast applied with incorporation to the whole watershed area (incorporation-no setback). The herbicides that were applied, are the same as the previous two studies; atrazine, metolachlor, and cyanazine. These were applied at rates of 2.24 kg/ha, 2.80 kg/ha, and 3.36 kg/ha, respectively. All the plots received tillage with a single pass of a tandem disk. For the non-incorporation treatments, this occurred before herbicide application, whereas for the incorporation treatment, disking followed herbicide application.

Three single stage samplers were used to sample inflow flowing into the terrace basin. The typical spacing and elevations are shown in Figure 5. Outflow from the terrace was sampled by using a hand pump and tygon tubing, placed in the tile inlet, approximately 15 cm below the soil surface. The goal for each rainfall/runoff event was to obtain from one to three samples of inflow and one to five samples of outflow per watershed per event, depending on the volume of the runoff/pondage. Total runoff amounts were estimated by using stage-recorded depths from one of the subwatersheds and data from a topographic survey. Four events occurred over a 53 day period of time following herbicide application, with the first event occurring 31 days after application. These events ranged from 2.24 cm (0.88") to 17.2 cm (6.8") of rainfall. The total amount of rainfall that occurred before the first runoff event was 11.8 cm (4.56"). The percent herbicide loss from the terraces after the four events is given in Table VI.

Table VI. Percent herbicide loss from the terraces after four runoff events.

No Setback			Setback			Incorporation-No Setback		
atra	meto	cyan	atra	meto	cyan	atra	meto	cyan
3.16%	1.65%	1.54%	3.48%	1.80%	1.56%	3.68%	1.40%	1.49%

Due to the long period of time before the first runoff event, the benefits of herbicide incorporation were minimized when compared the other treatments; due to the movement of the herbicides out of the mixing zone, or top layer of the soil surface. The advantages of incorporation relate directly to the reduction of herbicide in this mixing zone, since a smaller amount of herbicide is in contact with the runoff water. The incorporation - no setback treatment on the average did not reduce herbicide outflow concentrations or losses versus the no setback treatment for the four events. However, incorporation did reduce concentrations in the outflow for metolachlor and cyanazine. The benefits of the setback treatment was not evident in this study beyond what would be expected from the reduction of area treated.

Conclusions

From the four studies discussed, it is evident that buffer strip can be effective in reducting herbicide losses in runoff from a field, particularly if covers with vegetation. A major factor in determining this effectiveness is the field runoff area to buffer strip area ratio. As this area ratio increases, the effectiveness of the buffer strips in retaining herbicides decreases. Other factors related to the efficiency include: antecedent soil moisture content, soil texture, herbicide concentration levels in the runoff, herbicide adsorption potential to sediment and organic matter, plant population, and buffer strip slope. Buffer strips should be consider a best management practice that could be used in conjunction with other BMP's to reduce herbicide and sediment losses. These might include: contour farming, strip cropping, conservation tillage, herbicide incorporation, terraces, and etc. Additional research needs to address the effectiveness of buffer strip when looking at nutrient and weed seed losses from a field. Various vegetation species also need to be evaluated for increased retention within the strips and as a potential cash crop.

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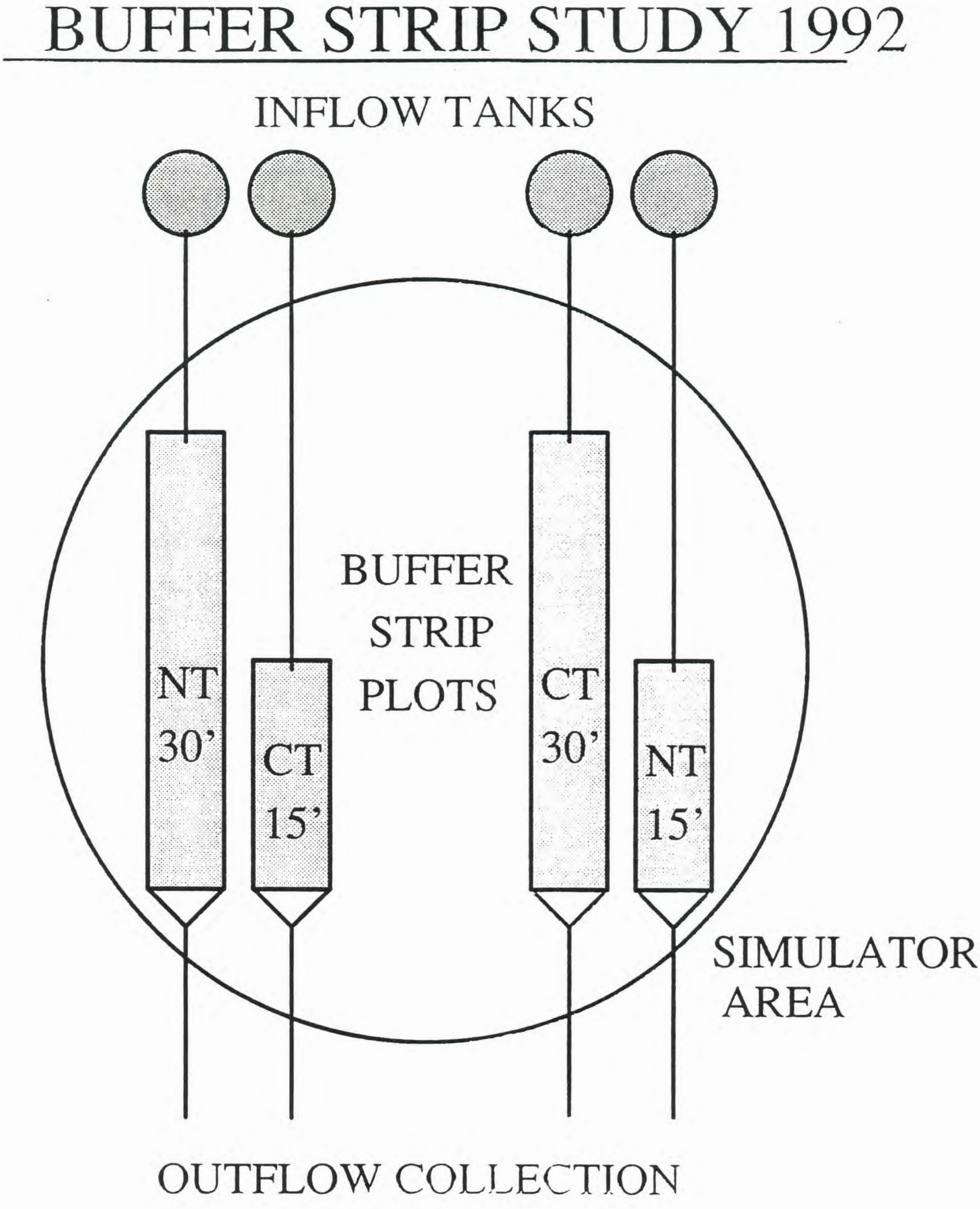

Figure 1. Typical rainfall simulation setup for the 1992 study.

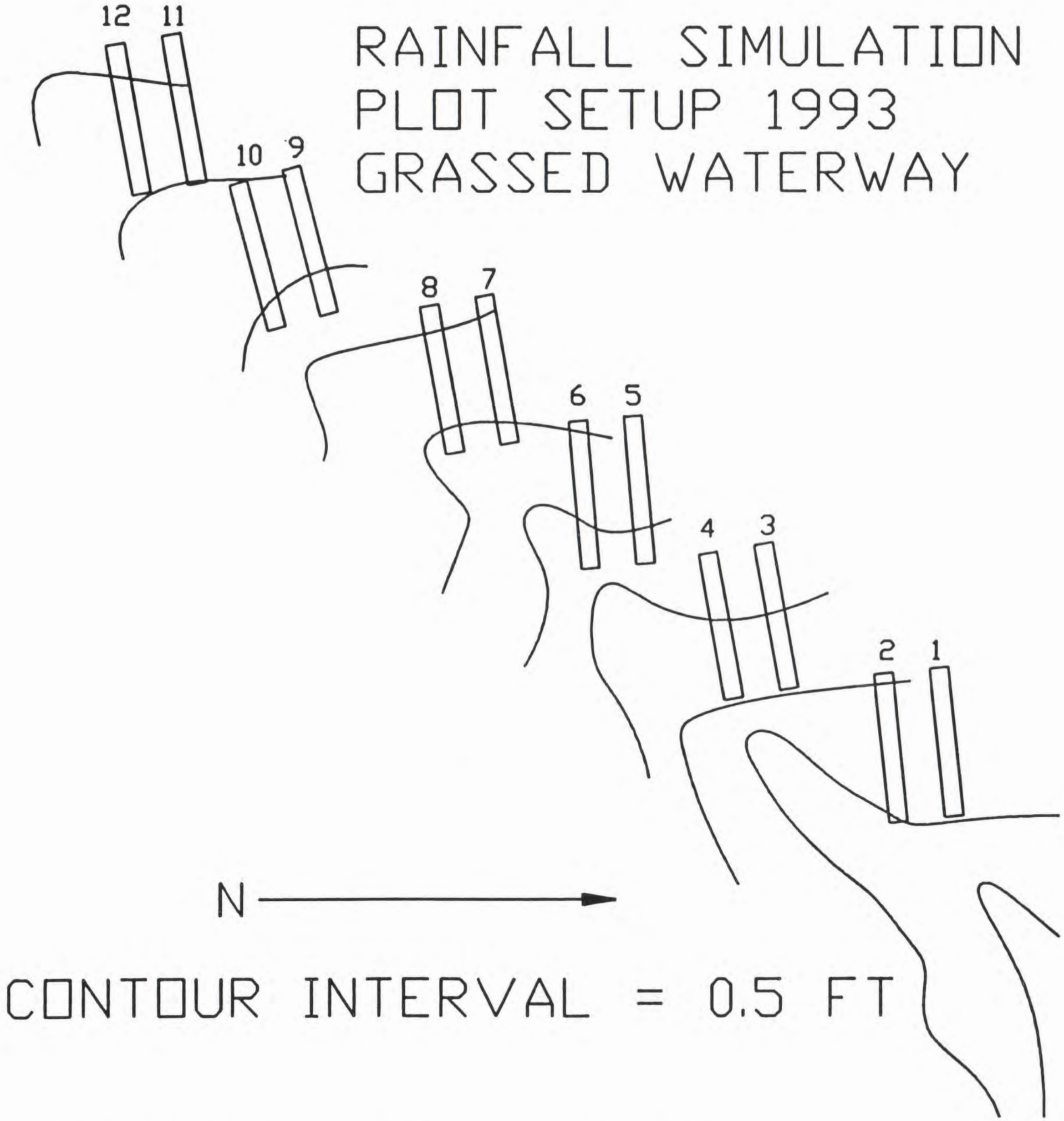

Figure 2. Plot setup for 1993 simulated rainfall study.

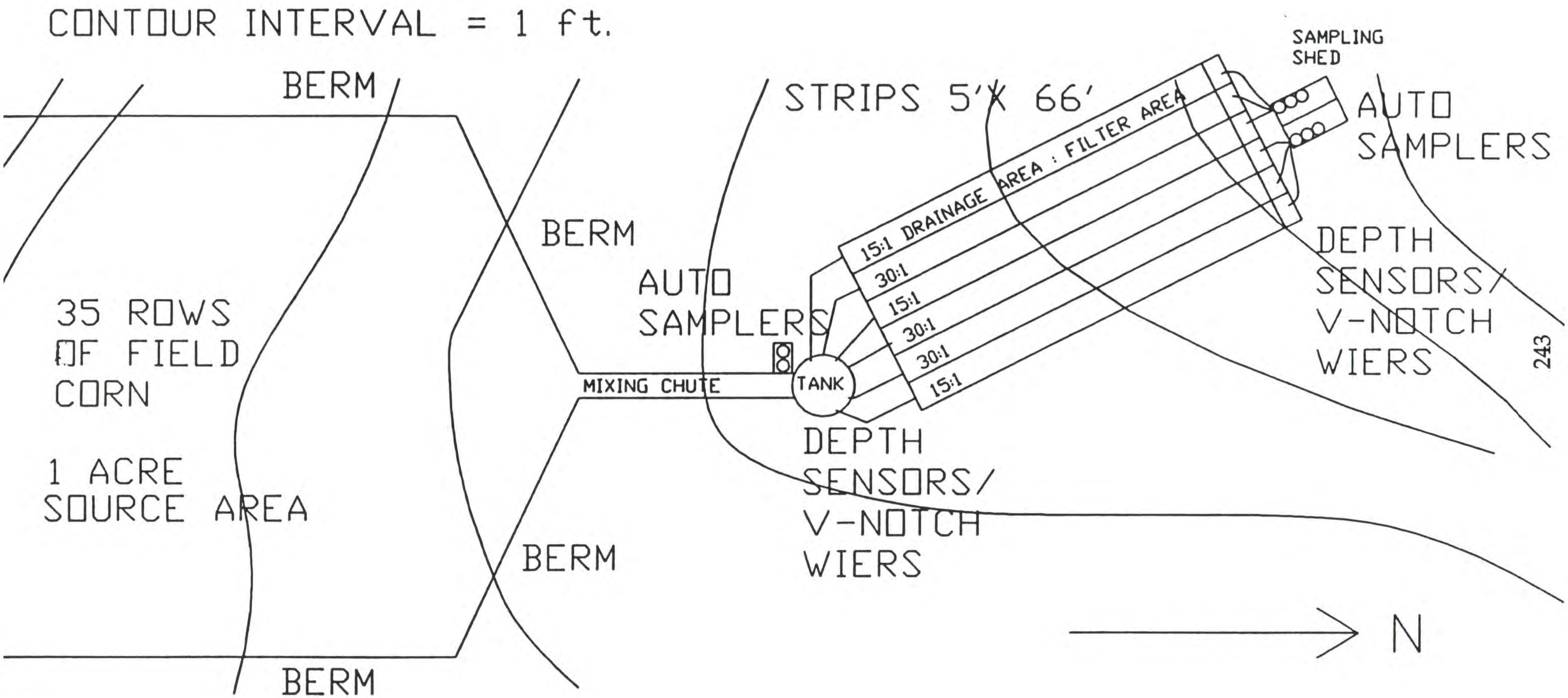

Figure 3. Field and plot setup for 1993 natural rainfall study

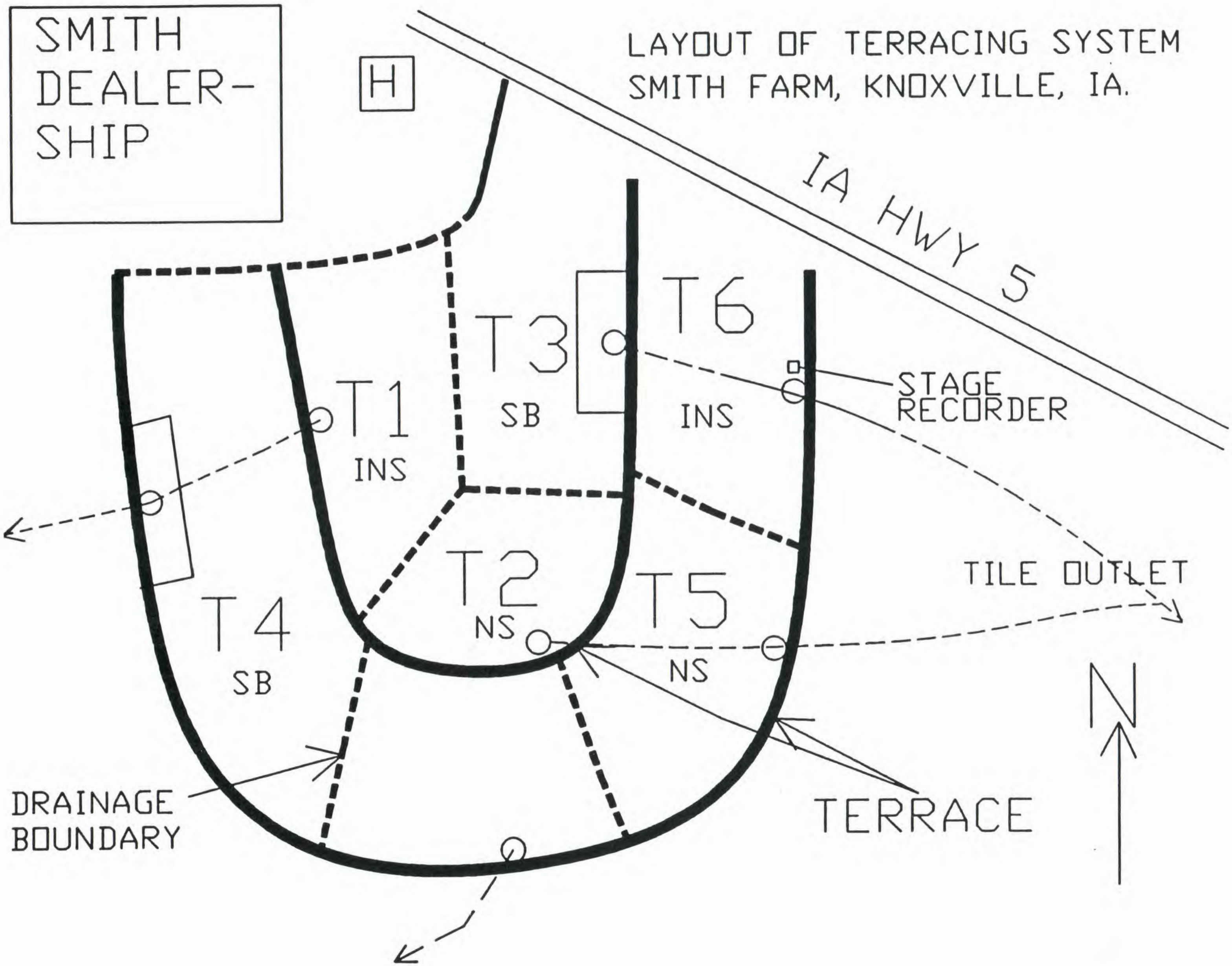

Figure 4. Layout of six subwatersheds on Smith terrace system NS = No Setback, S = Setback, and INS = Incorporation - No Setback

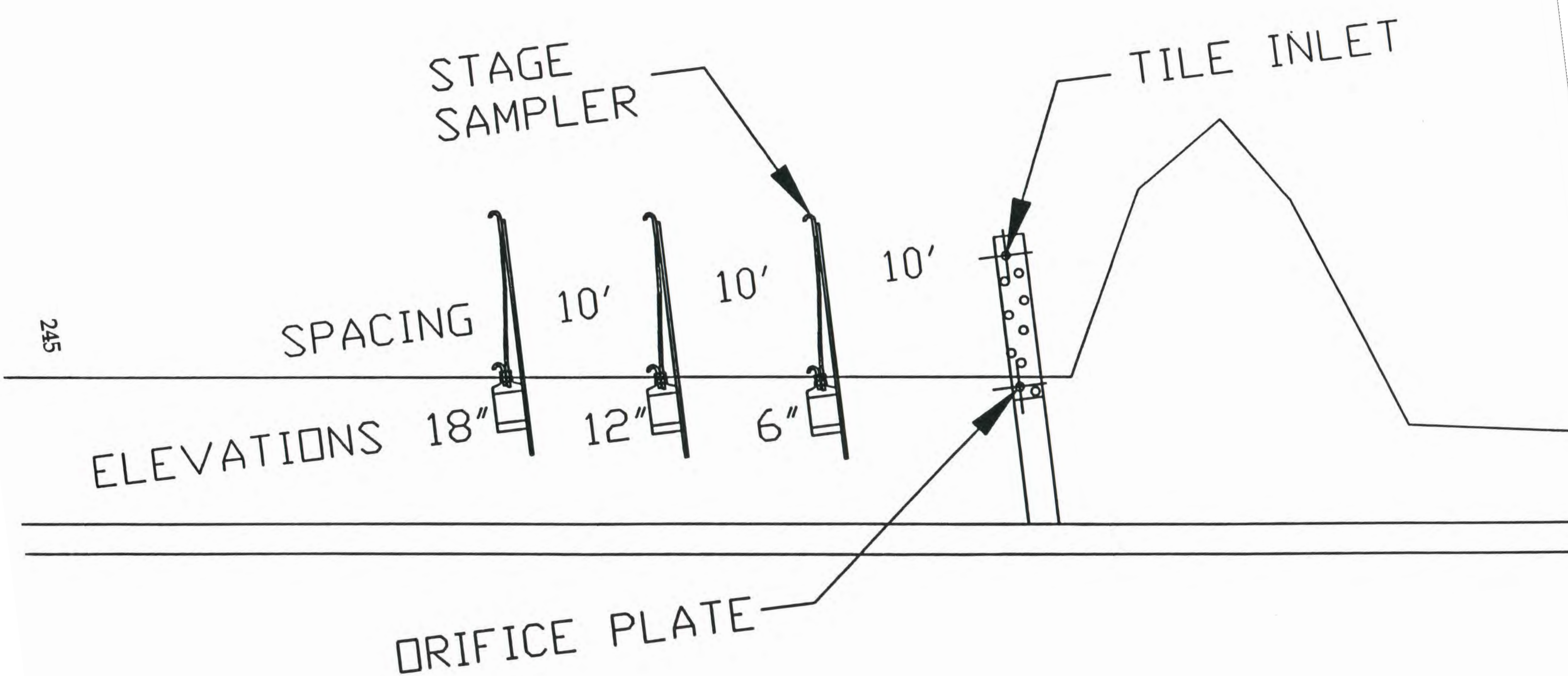

Figure 5. Typical locations of three single-stage samplers in terrace basin.